plasm is seen, otherwise with the same appearance as in the first stage.

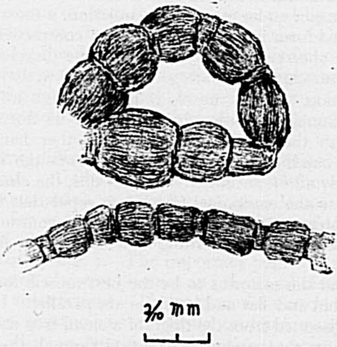
In still later stages the cytoplasm may begin to take on a violet or reddish hue, and granules begin to appear, when we must class the cell as a myelocyte. All grades between the diffuse-looking stamm-zellen and the fully granulated myelocyte may be noted.

ON THE MECHANISM OF THE CONTRACTION OF VOLUNTARY MUSCLE OF THE FROG.

By Edward B. Meigs,
of Philadelphia.

As a first step in the search for a mechanical explanation of muscular contractility, it is necessary to have a definite idea of the change of form which takes place in a muscle fibre when it contracts. For various reasons I have used frog's voluntary muscle in nearly all of my experiments. It is well known that when a fresh frog's muscle is placed in distilled water it goes into a state of complete and lasting contraction called water rigor. If a muscle in water rigor be carefully teased, some of its fibres will generally be found in the condition shown by Fig. 1.

Fig. 1.



Muscle fibres in water rigor.

Fig. 1 is a drawing of two fibres from a frog's sartorius in water rigor. The drawing was made with the camera lucida, and the outlines are, therefore, as true to nature as possible. The upper fibre has been bent almost into a circle by the teasing, while the lower one is nearly straight. The specimen from which Fig. 1 was drawn was prepared as follows: The sartorius was dissected from the thigh of a freshly killed frog and placed in distilled water for about ten minutes. It was then carefully teased in a little water on a glass slide, the excess of water was removed, and a drop of glycerin applied. The preparation was then covered with a cover-glass, which was cemented to the slide with asphalt. The teased fibres were examined under the microscope in water before the glycerin was applied, and they were then seen to present the same appearance as in the drawing, except that the distended portions of the lower one were as symmetrically globular as those of the upper one in the drawing. I do not know why the glycerin caused the irregularity of outline of the lower fibre without affecting the upper one.

I have treated a number of muscles in the manner described and I have almost always been able to obtain some fibres from each muscle in the beaded condition illustrated; but in no case have I found more than a small proportion of the fibres of a muscle in this state. The following, however, will show that the beaded is the true form of contracted muscle.

It is universally acknowledged that the contraction of muscle under electrical stimulation is the same as the normal contraction, and, therefore, if fibres can be shown to take the form of Fig. 1 when they contract under electrical stimulation, it must be admitted that the beaded form is the normal state of contracted muscle. It is not easy to observe beneath the microscope the change of form which frog's muscle fibres undergo during contraction due to electrical stimulation. If the muscle is large enough to be dissected out without damage, it is too large to allow its fibres to be seen clearly through the microscope. On the other hand, the least roughness in handling a small muscle destroys the irritability of all or of nearly all of its fibres. Besides this, the change from the uncontracted to the contracted form is so rapid that it throws the fibres under observation out of focus, and the contraction lasts at most only a few seconds, affording little time to get them in focus again.

I have found the sartorius to be the best muscle for this experiment. It is thin and flat and its fibres are parallel. If this muscle be carefully dissected from the thigh of a small frog and laid across the electrodes so that it can be observed through the microscope, the straight outlines of the fibres and the cross-striations can be distinctly seen. If now the tetanizing current be applied, the fibres will probably fly out of focus. But if they are quickly brought back into focus, it will be seen that their outlines are no longer straight, but that they have taken the beaded form.

After a muscle lying on a pair of electrodes with its ends unattached has been thrown into tetanus, it never again completely relaxes, but remains shorter and wider. This can be distinctly seen if the muscle be watched with the naked eye, and the fact is a great help in the observation of contraction. For, after the first application of the tetanizing current, the fibres, being already partially contracted, move to a much less extent with each subsequent application, and remain in focus, provided the objective used be of reasonably low power. If the tetanizing current be weak, and if it be applied for only short periods, the fibres may be seen with the microscope to contract and relax again and again, and the beading of the fibres can be seen to increase when the current is applied, and to diminish when it is removed. Of course, this beading of the fibres under electrical stimulation can only be seen at the cost of a good deal of care and trouble. I have again and again been disappointed by finding that the irritability of the fibres under observation has been completely lost; but I have repeatedly observed the increase and diminution of the beading on application and removal of the tetanizing current, and I have never seen a mere broadening of the fibres on application of the current and a narrowing on its removal.

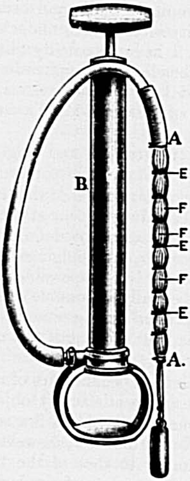
It must be said, in passing, that the constrictions and bulgings of the contracted fibres cannot be regarded as "waves of contraction." As the bulgings do not entirely disappear on removal of the tetanizing current, it can easily be seen that they always occur at the same points. This seems to show that they are caused by definite structural peculiarities of the fibre. Moreover, the bulgings remain stationary during the flow of the current. It is impossible to conceive a stationary wave of any sort, and equally impossible to believe that "waves of contraction" could be present during tetanus, which is a state of complete contraction throughout the length of a muscle fibre.

It is, of course, difficult to observe the finer peculiarities of muscle fibres in tetanus. A whole muscle is an unsatisfactory object for microscopic examination, and the tetanus can last but a few seconds at most. As far as I have been able to discover, however, the appearance of fibres in tetanus is similar to that of the beaded fibres illustrated by Fig. 1. The important points of similarity are the disappearance of the cross-striæ and the great distance between the contiguous constrictions. The portion of a muscle fibre between two contiguous constrictions evidently contains many cross-striations, for the distance between two contiguous striæ is not more than a tenth of the diameter of the muscle fibre, whereas the distance between two constrictions is nearly equal to the diameter of the contracted fibre at its widest part.

It may be that observations similar to mine have been already recorded, but I have examined a good deal of the literature of the subject and have not been able to find any reference to the fact that frog's voluntary muscle fibres take the beaded form when they contract. Ranvier,[1] however, mentions the fact that the fibrils of insects' wing muscles often present the beaded appearance. But whether the facts have been recorded or not, they demand more consideration than they have hitherto received.

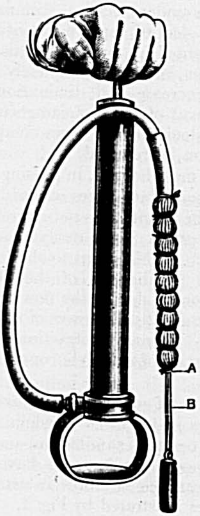
I shall now give what seems to me the most probable explanation of contraction. It is based partly on the observations recorded above, but the correctness of the observations is not affected by the probability or improbability of the explanation. I shall begin by showing that if the muscle fibre be assumed to have a certain mechanical structure, the phenomena of water rigor may be explained on perfectly well-known mechanical and physical principles. I can best describe the structure by exhibiting drawings of a model.

FIG. 2.



Fibre model.

FIG. 3.



Fibre model contracted.

Fig. 2 represents a model supposed to have the structure of a muscle fibre. *A A* is a tube of thin rubber, encircled at intervals by wire rings, *E E E*. Along the tube run inelastic cotton threads, *F F F*, each of which is attached to all of the wire rings. *B* is an air-pump, by which air can be forced into the tube *A A*. When this is done the model takes the form shown by Fig. 3. Each of the divisions of the tube between the wire rings tends to become spherical, the cotton threads are thrown into curves, and, as they are nearly inelastic, the whole structure necessarily shortens. The illustrations are reproduced from photographs of the model taken at equal distances from it, so that the relative dimensions are preserved; the distance between the lines *A* and *B* (Fig. 3) represents the amount of the shortening.

---

[1] Leçons d'anatomie générale sur le système musculaire.

It will be necessary now to return a step and consider what are the most obvious changes that take place when a fresh frog's muscle is placed in distilled water. These changes may be summed up as follows: The muscle absorbs water, it contracts, and its fibres change from the cylindrical to the beaded form. It may be proved that the muscle absorbs water by weighing it before placing it in the water and afterward. It will be found to be heavier afterward. The contraction of the muscle is remarkable in several ways. It is very slow, for about fifteen minutes elapse before it is complete; it is almost exactly equal to the greatest contraction that can be obtained with the tetanizing current; and once complete it lasts indefinitely.

The absorption of water by the muscle may be explained by the laws of osmosis. The shortening of the fibres and their change of form are immediately explained if they are supposed to have a structure mechanically equivalent to that of the model. For if they had this structure, the water passing into them by the osmotic process would compel them to change from the uncontracted cylindrical form to the contracted beaded form, exactly as air forced into the model compels it to change from the form shown by Fig. 2 to the form shown by Fig. 3. When the osmotic process is complete there is no tendency for it to reverse itself, and the muscle therefore remains contracted for an indefinite time.

There is one mechanical fact which greatly strengthens the argument. It is a necessary part of the construction of the model that the distance between the wire rings should bear the same relation to the diameter of the tube as shown by Fig. 2. Suppose that all of the wire rings except those at the top and at the bottom of the tube were removed, and that the threads and the rest of the machine were left as before, a much greater amount of air would then have to be forced into the tube before the curvature of the threads and consequent shortening of the model was as great as in Fig. 2; for the whole tube would tend to take the form of a sphere, and before it could assume this shape the rubber at the middle would have to stretch enormously, and the diameter at that point would be very great. On the other hand, practically no shortening can be produced in a machine with its rings much nearer together than those of the model (Figs. 2 and 3). It is a striking coincidence that the constrictions of the fibres in Fig. 1, the constrictions of frog's fibres in electrical tetanus, and those of the fibrils of insects' wing muscles are all at just such distances that the greatest amount of shortening can be obtained with the least expansion in volume and with the least stretching of the fibre sheath.

The four preceding paragraphs may be summed up as follows: All of the phenomena of water rigor may be explained on perfectly well-known mechanical and physical principles, if it be assumed that the muscle fibre has the same structure as the model shown by Figs. 2 and 3. It is known that water passes into the fibres by osmosis while the muscle is going into water rigor, and if the fibres have the structure in question, this passage of water into them is sufficient to cause both the change of form and the shortening. As the phenomena of water rigor can be explained by so simple an assumption, I have thought it justifiable to make the assumption.

The fact that so few of the fibres of a muscle in water rigor can be found in the beaded condition is, of course, a strong counter-argument, but it must be remembered that distilled water is a reagent extremely destructive to muscular tissue. If the antenna of a living fresh-water snail be cut off near its base it will immediately contract. If it be then examined under the microscope in a little water, constrictions and bulgings are seen, not unlike those of the contracted muscle fibres. After a quarter of an hour the constrictions become much shallower and fainter, although the total length of the organ remains unchanged; and after half an hour or an hour they completely disappear. It seems quite possible that the constrictions of the muscle fibres are acted upon by the water in the same way as those of the snail's antenna. When it is added that fibres in electrical tetanus invariably present the beaded appearance, the fact that many fibres from muscles in water rigor do not present that appearance becomes insignificant.

If my explanation of water rigor is correct, it suggests very important conclusions. The structure which I have attributed to the muscle fibre is a highly specialized one, and it is apparently designed for the purpose of producing contraction. Besides this, it evidently acts when a muscle is thrown into tetanus by the electrical current, for fibres in tetanus exhibit the beaded form. The conclusion is inevitable that the structure in question is part of the mechanism of contraction.

To produce contraction in a structure like the model, it is necessary to increase the volume of the contents. There are only two ways in which this increase could be accomplished in muscle fibres. Either the contents of the fibres might expand or fluid might pass into the fibres from without. If contraction were caused by an expansion of the contents of the muscle fibres, it would necessarily be accompanied by an increase in the volume of the muscle. But it is known that the volume of a muscle does not increase during contraction, and it cannot, therefore, be supposed that contraction is due to the expansion of the contents of the muscle fibres. If, therefore, the muscle fibre contracts in the same manner as the model, it is necessary to suppose that its contraction is caused by the passage of fluid into it from without.

It is thus seen that a consideration of the phenomena of water rigor and of the change of form which frog's muscle fibres undergo during contraction leads to the conclusions that the fibres have a certain mechanical structure which causes them to contract when the volume of their contents is increased, and that the ordinary contraction of muscle is caused by the passage of fluid from the spaces between the fibres into the fibres. (For convenience, I shall hereafter call the spaces between the fibres the interfibrous spaces.) It may be asked whether this conclusion in any way helps to explain muscular contraction. I believe that it does, for the passage of fluid from one part of an organ to another is a process which is quite likely to be explained on the principles of inorganic chemistry. There are several analogous processes, such as diffusion and osmosis. And besides this, the passage of fluid from one part of an organism to another is probably the most widely distributed and elementary process in the organic world. Plants universally receive their nourishment and grow by this process; it may be observed in the amœba during the extrusion of a pseudopod; and in the higher animals it takes place in the digestive tract, in the vascular system, in the kidneys, and in all of the glands. Not only this, but there is good reason to believe that this process is the cause of the movements of the insectivorous plants[1] and of Mimosa pudica.[2]

The points of similarity between muscles and glands have received some notice from physiologists. Rosenthal mentions these similarities in the work quoted above (see pp. 212 and 213). They are: first, the fact that both muscles and glands are thrown into action by stimulation of their nerves, and, second, certain likenesses in the electrical reactions. The following experiment seems to show a striking histological similarity. If one of the voluntary muscles be dissected from a freshly killed frog and immediately frozen and cut into thin transverse sections the sections present the appearance of Fig. 4, which was drawn from such a section with the camera lucida.

The striking part of the appearance of Fig. 4 is the segmented ring of darker tissue which surrounds each of the fibres, and which resembles a layer of secreting cells. The fact that transverse sections of muscle prepared by the freezing process resemble sections of glandular tissue supports my hypothesis in the following manner: I have been endeavoring to show that the contraction of muscle is due to the passage of fluid from the interfibrous spaces into the fibres. The activity of a gland is secretion, which consists in the passage of fluid from the interacinous spaces into the acini, whence it is discharged through the ducts. In other words, according to my hypothesis, there is a fundamental likeness between the function of a muscle fibre and the function of a gland acinus. And if, in addition to this, there is a strong histological likeness between the two tissues, the fact constitutes a considerable addition to the argument.

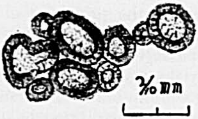
---

[1] Charles Darwin. On Insectivorous Plants, London, 1875, second thousand, p. 255.

[2] I. Rosenthal. General Physiology of Muscles and Nerves, London, 1881, pp. 2 and 3.

The appearance of Fig. 4 can always be obtained by the following method: A frog is killed, the sartorious is dissected out, frozen, and cut into sections without being put in any reagent, and all this is done as quickly as possible. The sections may be floated out in a 0.6 per cent. sodium chloride solution or in distilled water and examined with the microscope. They will then be seen to have the appearance of Fig. 4. Such sections may be preserved in glycerin. Alcohol produces a great decrease of the sharpness of the appearance. In very warm weather it is necessary to cool the frog with ice before killing it, and to dissect out the muscle and freeze it even more quickly than in cooler weather.

FIG. 4.



Cross-section of muscle prepared by the freezing process.

Whether the appearance presented by Fig. 4 or that of sections of muscles which have been preserved in alcohol or some other fixative, and have then been mounted by the paraffin or celloidin method, is more truly representative of the condition of frog's muscle during the life of the animal must be left to the judgment of scientific men. The answer to the question will depend on the answers given to two subordinate questions. First, Is the freezing process or is the alcohol and paraffin process likely to be more destructive? Second, Is the appearance of Fig. 4 or that of sections prepared by the alcohol and paraffin process more suggestive of mutilated tissue? In discussing the first question it must be said that frog's muscle may be frozen and melted again and immersed for a considerable period in 0.6 per cent. salt solution without losing its irritability.[1] The process by which the appearance of Fig. 4 is obtained can be completed within ten minutes of the death of the animal from which the tissue is taken, and no reagent capable of destroying the irritability of the tissue is used. On the other hand, the alcohol and paraffin process requires many days for its completion, and any one of the reagents used is capable of destroying the life of the tissue.

---

[1] American Text-book of Physiology, Philadelphia and London, 1901, 2d ed., vol. ii. pp. 58 and 162.

It is difficult to discuss the question whether the appearance of Fig. 4 or that of alcohol and paraffin sections is more suggestive of mutilated tissue. Every histologist feels capable of judging from appearance alone which of two specimens of the same tissue is the more perfect, and yet it would be difficult for him to say on what he based his judgment. The distinctness of the outlines and the amount of differentiation in each of the specimens are, perhaps, the most important points to be considered. The sections illustrated by Fig. 4 certainly show more differentiation than the alcohol and paraffin sections. In Fig. 4 the fibres appear to be made up of two distinct parts, the central disk and the peripheral ring, and the latter is evidently divided into segments. In the alcohol sections each fibre appears as a nearly homogeneous disk. It is easy to imagine that the mutilation of a tissue whose true appearance was that of Fig. 4 might produce the appearance of the alcohol sections; but difficult to suppose that the mutilation of a tissue whose true appearance was that of the alcohol sections might produce the appearance of Fig. 4.

There is one difficulty which must be briefly considered before the conclusion of this discussion, namely, that the action of muscle is extremely rapid, whereas the process of the absorption of fluid is commonly regarded as a slow one. But the unusual conditions under which absorption takes place in muscle must be kept in view. The largest muscle fibres are in reality the merest threads, each of them is entirely surrounded by fluid, and there is, therefore, in every muscle a very large surface exposed by the fibres in comparison to the small amount of fluid to be absorbed by them. The finest cotton thread is exceedingly thick in comparison with even the largest frog's muscle fibre, and yet a cotton thread cannot be dipped in water for a fraction of a second without becoming saturated. The saturated thread has absorbed at least half its volume of water, and this is much more proportionally than would be required to cause complete contraction in a muscle fibre with the structure of the model. But a stronger argument can be adduced against the assumption that the contraction of muscle cannot be due to the movement of fluids because the fluids cannot be conceived to move sufficiently rapidly. If nothing further be conceded regarding the constitution of muscle than that it is composed of solids and fluids, it must be admitted that the fluids move whenever the muscle contracts; and the fluids could surely be moved by chemical processes as rapidly as by the movement of the solid parts of the muscle.

If I knew nothing further about muscle than that it was composed of solids and fluids and had the power of movement, it would seem to me much more likely that the movement of the fluids caused the movement of the solids than that the movement of the solids caused the movement of the fluids. The former is the case in every machine made by man for the purpose of converting chemical into mechanical energy.

I realize that my conclusions are opposed to the latest results of scientific research, in so far as these seem to show that muscle fibres are composed of fibrillæ. If frog's muscle fibres are composed of fibrillæ, which are independently capable of contraction, the whole of the foregoing argument falls to the ground. I hardly dare to urge my own observations against those of such an authority as Rollett, and yet everything that I have seen seems to me opposed to the view that the muscle fibres are composed of fibrillæ. The appearance of the cross-section of frog's muscle, of which a drawing has been submitted, goes to show that fibrillæ do not exist in frog's muscle; and the beaded appearance of contracted fibres, whatever construction may be put upon it, seems to favor the idea that the fibre is the contractile unit. It may be urged that most of the work which tends to prove the existence of fibrillæ has been done with other muscle than the voluntary muscle of the frog, and the evidence favoring the existence of fibrillæ in frog's muscle is very unsatisfactory. It depends on the appearance of the muscle and on certain results to be obtained from specimens hardened in alcohol. Leaving aside the argument that appearance alone can never be a very satisfactory indication of mechanical structure, it must be conceded that the exact appearance of the interior of a fresh frog's muscle fibre is not very accurately known. Great amplification must be used to see the details of the structure which are supposed to represent fibrillæ, and with a high power little more than the upper surface of a thick frog's fibre can be sharply seen. As for the fact that frog's fibres may, after a long immersion in alcohol, be teased into much smaller fibrillæ, there is no evidence to show from which part of the fibre these fibrillæ come. They may be merely portions of the fibre sheath. And there is a good deal of direct evidence to show that the interior of fresh frog's muscle fibres is in a fluid or semifluid state.

Sir Michael Foster[1] mentions the classic instance of the nematode worm seen making its way through the centre of a fibre. And Rosenthal[2] says: "It can be shown that a muscle fibre when recently taken from the living animal must, in reality, be of a fluid, or, at least, of a semifluid nature. So that it is impossible to affirm that either the discoid or the fibrilloid structure actually exists in the muscle fibre itself; it must rather be assumed that both forms of structure are really the result of the application of reagents, which solidify the originally fluid mass and split it up in a longitudinal or transverse direction."

---

[1] M. Foster. Text-book of Physiology, London and New York, 1891, 5th ed., part i., p. 95.
[2] General Physiology of Muscles and Nerves, London, 1881, p. 14.

It will probably be a long time before an adequate comprehension of the mechanism of muscular contraction is attained, and it is not to be expected that the subject could be completely elucidated within the limits of a single paper. I have simply pointed out the explanation which, after a consideration of the various facts, would seem to be the most likely one.

OBSTRUCTION OF THE CENTRAL RETINAL ARTERY.[1]

REPORT OF A CASE.

By William T. Shoemaker, M.D.,
of Philadelphia.

The question of embolism versus thrombosis of the central retinal artery has for a great many years been discussed and argued until it might be said to be almost threadbare; and, curiously enough, many of the best observers have titled their cases embolism, while declaring their belief in probable thrombosis. That this question is still an unsettled one in medicine is sufficient apology for further contributions.

The following case I believe to be one of lateral thrombosis of the central artery of the retina. The evidence to be adduced, though not conclusive, strongly favors such a diagnosis.

F. W., aged seventeen years, twister in a mill, came to the Eye Clinic of the German Hospital November 18, 1903, with history as follows: One week ago, while returning home from a matinee, she suffered a sudden attack of partial blindness in the left eye. This was described as everything becoming black before O. S., except in the lower field, where vision remained. Subjectively she noticed that the top of the head of a person looked at was not seen. The condition did not improve, but, on the contrary, she thinks became worse in the succeeding few days. The attack was neither preceded, accompanied, nor followed by vertigo, headache, or any physical discomfort whatever. An interesting event in the history of the attack which must be considered, though it is, perhaps, a little sensational, is the following: The play which she witnessed was an extravagant melodrama, in which the heroine, during the third act, became suddenly blind, and continued so until the end of the play, with dramatic effect. The patient was much impressed, and, as she expressed it, could not get the afflicted heroine out of her mind. While thinking of this accident, she had proceeded but three squares from the theatre when her own trouble commenced.

---

[1] Read before the Ophthalmological Section, College of Physicians, December 15, 1903.